GALILEO SATELLITE TOUR: ORBIT DETERMINATION PERFORMANCE

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The Galileo mission is an ambitious attempt to explore the Jovian system by spacecraft. This voyage of exploration is a logical successor to the reconnaissance voyages of Pioneers 10 and 11, Voyagers 1 and 2, and Ulysses. These spacecraft merely flew past Jupiter, spending relatively little time in its system. Galileo differs from these earlier spacecraft in that it will remain within the Jovian system, studying the planet and its four major satellites for a period of two years.

Insertion into orbit around Jupiter will occur on December 7, 1995. The portion of the mission encompassing observations of Jupiter and the major and minor satellites, and magnetospheric mapping, has become known as the Jovian tour. During this period Galileo will encounter each of Europa, Ganymede, and Callisto at least three times on trajectories that will bring it to altitudes from 200 to 3100 kilometers. The availability of precision navigation permits flight controllers to exploit gravity-assists throughout the tour. This reduces propellant expenditure and enables a ten encounter tour within a period of sixteen months. Furthermore, the ten encounters occur on eleven highly eccentric orbits -- orbits with extended major axes which will elucidate Jupiter's magnetosphere. Figure 1 illustrates the tour trajectory plot, and a summary of tour characteristics is provided in Table 1. So called non-targetted encounters are also listed in Table 1. These are designated by adding an "A" to the encounter number. Non-targetted encounters have higher altitude flybys, as shown in the Table.

The Jovian satellite tour was designed for a fully functional spacecraft. Unfortunately, en route to Jupiter, Galileo's deployable high gain antenna (HGA) failed to open, leaving a single low gain antenna (LGA) as the spacecraft's sole telecommunication link.

This paper will assess orbit determination capabilities of the LGA mission. The tour in Table 1, while optimized for an HGA mission, will nevertheless remain for the LGA mission. Moreover, it will be shown that despite significantly degraded tracking data and a reduced picture budget, this tour will still be successfully navigated.

Propellant margin (P.M.), the quantity of fuel and oxidizer remaining after ten encounters, is a concern to flight controllers. Positive P.M. indicates a 90% probability of tour completion, whereas negative P.M. implies a probability of less than 90%. Delivery accuracies to each target satellite must be met in order to maintain a positive P.M. balance. Therefore to ensure a ten encounter tour, propellant usage must be guided by accurate orbit determination.

The HGA mission had a data rate capability of 115,000 bits per second (X-band) -- ample bandwidth to return science, navigation, and engineering data in near real-time. The LGA mission is expected to return only 40 bits per second over S-band frequencies. Due to the paucity of this LGA data and the priority of science data, severe limitations have been placed on acquisition of radiometric tracking data. Only a single track (eight hours) of two-way S-band Doppler data per week will be acquired.

Jovian distances preclude acquisition of standard S-band ranging data. Spurred on by Galileo's plight, a refined ranging formulation has recently been developed at JPL to overcome this limitation. This formulation, called pseudo-noise ranging, excells under adverse signal-to-noise conditions and shall be applied to the LGA Galileo tour.

Optical navigation images (opnavs) i.e. satellite images against a star background, were important for the HGA mission; they are critical in the LGA tour. The success of the LGA tour hinges on these opnavs. By employing newly developed image compression and editing techniques, up to thirty-five opnavs per orbit can be returned for inclusion in the orbit determination (vs. two hundred in the HGA mission) Newly developed on-board software will employ an editing strategy which retains the information content of each opnav, yet needs to return three orders of magnitude fewer bits to the ground.

Of almost equal value to the success of the tour is a newly-implemented, ground-based, Galilean satellite observing program. The goal of this multi-year program is to reduce the current pre-encounter satellite ephemeris uncertainty. This improved ephemeris will ultimately yield improved P.M.

Orbit determination of an LGA mission does degrade with respect to the HGA mission. But, with the aforementioned assumptions, a covariance analysis clearly demonstrates that an LGA Galileo can successfully complete its tour of the Jovian system. Thus, in spite of the telecommunications bit rate dropping nearly four orders of magnitude with the loss of the HGA, navigating the Galilean satellites remains an achievable objective for Galileo.

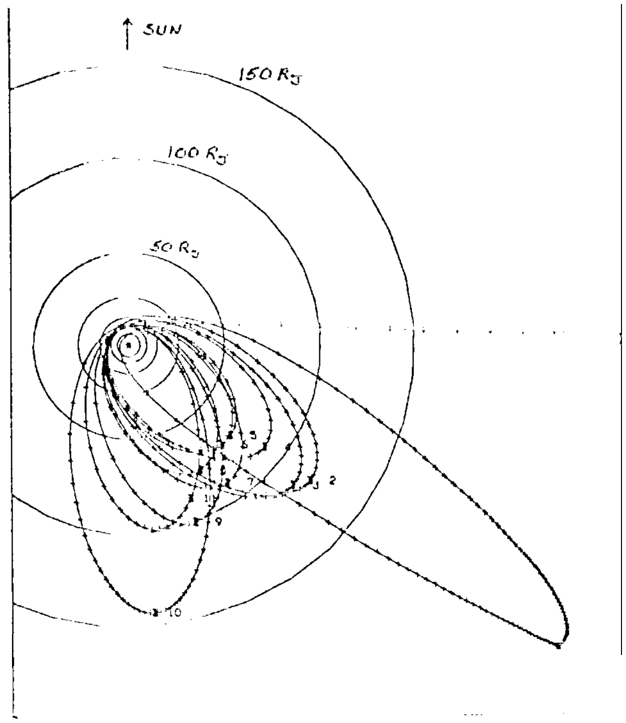

Fig. 1

ENCOUNTER	DATE/SATELLITE	INBOUND/ OUTBOUND	ALT. (KM)	LAT. (DEG)
G1	4 Jul 96/Ganymede	In	500	24
G2	6 Sep 96/Ganymede	In	200	84
C3	4 Nov 96/Callisto	In	1232	15
E3A	6 Nov 96/Europa	Out	65475	0
E4	19 Dec 96/Europa	Out	633	1
(E5A)	20 Jan 97/Europa	Out	25187	0
E6	20 Feb 97/Europa	In	635	-4
E7A	4 Apr 97/Europa	In	24988	-
G7	5 Apr 97/Ganymede	Out	2740	58
C8A	6 May 97/Callisto	In	35205	-40
G8	7 May 97/Ganymede	In	1602	29
C9	25 Jun 97/Callisto	In	414	1
G9A	26 Jun 97/Ganymede	In	76976	1
C10	17 Sep 97/Callisto	In	522	6
E11	6 Nov 97/Europa	In	1000	66

Table 1